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A MULTILEVEL DOUBLE LOOP APPROACH FOR THE DESIGN OF ONBOARD FLIGHT NETWORKS

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Abstract. After testing different existing design methods for complex problems, we have concluded that a good approach based on system decomposition must coordinate the design process of components to reach the system optimum. In this paper, we present a multilevel collaborative approach for designing complex systems based on several loops (here 2). A system level optimization loop added to lead optimizations of components at their optimal solutions. This method was applied to the sizing of a simplified embedded electric network with single source-load configuration.

Keywords: integrated design, collaborative multilevel optimization, embedded electrical system.

INTRODUCTION

Thanks to capabilities of optimization in solving nonlinear and multimodal design problems, and to face increasing system complexity, practitioners attempted to propose multilevel schemes [1], [2]. J.-F. M. Barthelemy proposed a classification of the multilevel optimization problems and identified several methods for solving certain classes of multilevel design problems [3]. He focused on two phases which are decomposition and coordination. Our works in GENOME project (optimized management of energy) allowed us to verify these conclusions and to add another key element: the “system level optimality”. Decomposing a system and coordinating sub-system designs is not enough to reach the optimum of the original non-decomposed system. Sub-system optimizations have to be guided to reach the best system solution [1], [2]. In this paper, we present a new multilevel method inspired by the design of embedded electrical system. An additional level of optimization is used to choose the best solutions among all feasible coordinated solutions.

I. PROBLEM CLASSIFICATION

The matrix of dependencies is a powerful analysis method that describes the couplings between functions and variables [3]. In some cases, the decomposition is imposed by confidentiality constraints that condition the work of each team in the global design process of the system. So, methods based on decoupling variables are not suitable to deal with such problems. In such cases, other formulations have to be proposed to manage coupling variables.

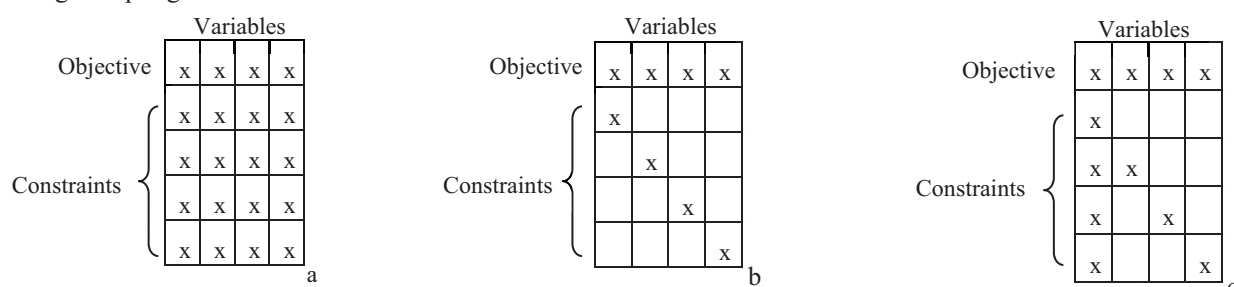


Figure 1. Dependency matrix with coupling variables: (a) block full, (b) block-angular, (c) quasi-block-angular

The second characteristic of the design problems often encountered in the design of embedded systems is that the objective functions at the system level can be expressed in terms of objective functions associated with each subsystem, e.g., the mass of an energy channel is the sum of all its components.

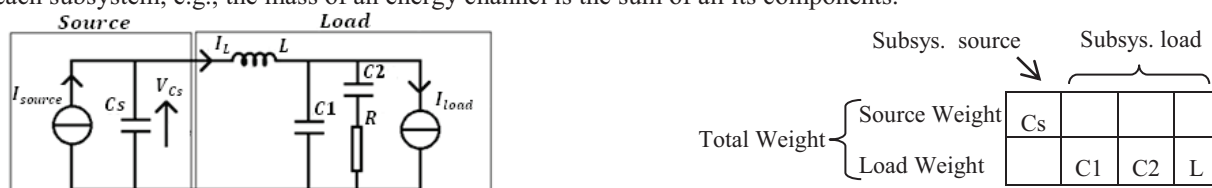


Figure 2. Objective function decomposition

II. MULTILEVEL DOUBLE LOOP METHOD

The original non decomposed problem depends of all design variables, each sub-objective function (W_{source} , W_{load}) depends on its own design variables, but constraints depend on all design variables.

$$(1) \quad \begin{cases} \min_{Cs, C1, C2, L} W_{tot}(Cs, C1, C2, L) = \min_{Cs, C1, C2, L} (W_{source}(Cs) + W_{load}(C1, C2, L)) \\ G_1(Cs, C1, C2, L) = V_{Cs_f} - V_{Cs_f}^{STANDARD} \leq 0 \\ G_2(Cs, C1, C2, L) = I_{L_f} \leq I_{L_f}^{STANDARD} \leq 0 \end{cases} \quad Cs, C1, C2, L \text{ are design variables}$$

Coupling variables (V_{Cs} , I_{L}) have to ensure coherence between subsystems: there are coupled between themselves and depend on design variables. Due to frequency model of subsystems, voltage and current harmonic at a given frequency are related by the transfer function which depends on filter parameters.

$$(2) \quad \begin{cases} V_{Cs_f} = l_1(Cs, I_{L_f}) \\ I_{L_f} = l_2(C1, C2, L, V_{Cs_f}) \end{cases} \quad V_{Cs_f} \text{ and } I_{L_f} \text{ are coupling variables of the system}$$

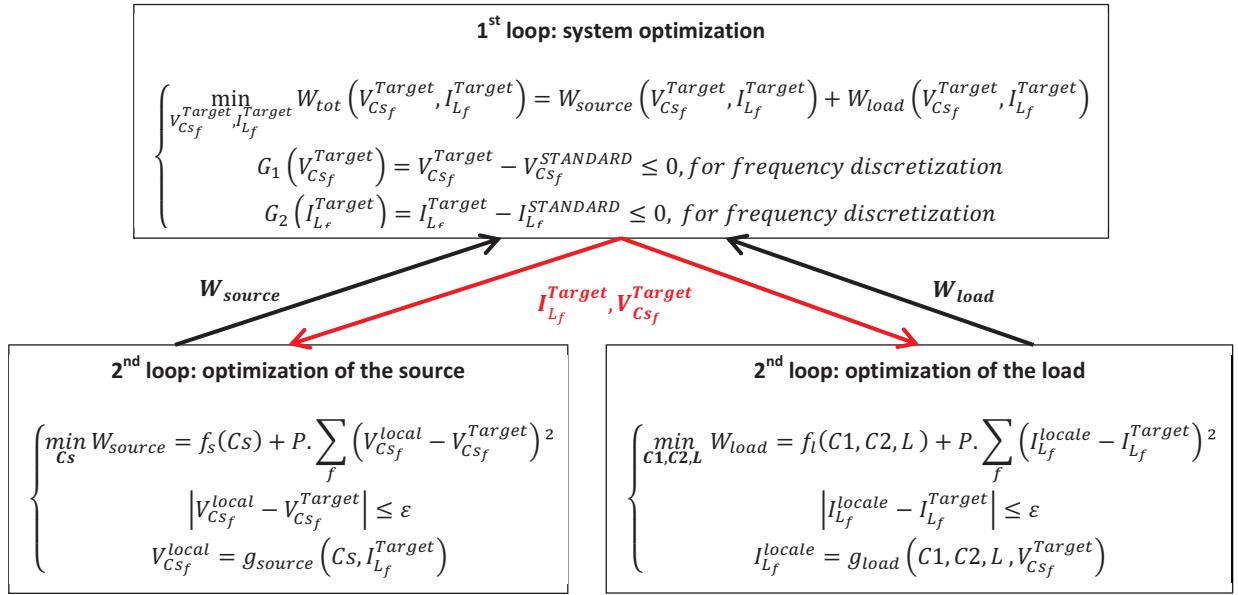


Figure 3. Architecture of the multilevel double loop optimization method

The proposed approach uses two levels of optimization. In the system level, the goal is to find values of coupling variables minimizing system level objective function. Each component optimization search the best solution in terms of design variables, but targeting coupling variables proposed at system level.

In the sub-system optimization, each optimization try to find the local optimum which respect to the values of coupling variables. The sub-objective function is penalized if targets on coupling variables are not fulfilled: in such a case, a penalty function is sent to the system level. The penalty term (P) must be very high in order to avoid the non-feasibility of the solution. With this configuration, the system level has to find feasible (P=0) and optimal design.

Table 1. Objective function value

| Simultaneous design approach | | Multilevel double loop approach | |
|------------------------------|-------|---------------------------------|-------|
| Number of evaluations | 500 | Number of evaluations | 10000 |
| Total weight (kg) | 0.840 | Total weight (kg) | 0.839 |

Using a genetic optimization algorithm we were able to converge at the same optimal solution found by using a simultaneous optimization on a whole system. The number of evaluation of subsystems was:

$$(3) \quad N_{ev.} = N_{ev. at system level} \times 2 \times N_{ev. at subsystem level}$$

Without knowing the internal models of subsystems, we managed to find the optimal system solution by exchanging only on data networks that are common to subsystems.

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